Effects of different cooking treatments on flesh fatty acid composition of total lipids in farmed Sea bass *Dicentrarchus labrax* (Moronidae)

by

Amira MNARI BHOURI* (1), Hanene JRAH HARZALLAH (2), Madiha DHIBI (2), Imen BOUHLEL (1), Mhamed EL CAFSI (3), Mohamed HAMMAMI (2) & Abdelhamid CHAOUCH (1)

ABSTRACT. - The aim of this work is to compare the effects on flesh lipids and fatty acids in farmed Sea bass (*Dicentrarchus labrax)* of different cooking treatments: boiling, oven cooking and frying in corn oil (FWSO) and sunflower oil (FWCO). Fatty acid contents in muscle of fresh (control), boiled, oven cooked, FWSO and FWCO farmed Sea bass collected from Tunisian Station of Aquaculture (Hergla, Tunisia) were analysed. Total lipids were extracted with chloroform and methanol. Fatty acid methyl esters, obtained using KOH in methanol and hexane, were analysed using capillary gas chromatography. The descriptive statistics and one-way analysis of variance were conducted. The significance level was selected at $p < 0.05$. Our results revealed that raw farmed Sea bass was rich in polyunsaturated fatty acids (PUFA) n-3, particularly eicosapentaenoic (EPA) and docosahexaenoic acids (DHA), resulting from the abundance of these fatty acids in food. After boiling and oven cooking, total lipid decreased by 55% and 39%. After frying with the two oils they increased from 86.6 to 120 and 150 mg/g of tissue fresh weight ($p < 0.05$), respectively. Saturated fatty acids (SFA) decreased significantly in FWSO and FWCO Sea bass ($p < 0.05$) from 31.54% of total fatty acids (TFA) to 17.54% of TFA and 17.97% of TFA but increased in boiled and oven cooked fish (32.42% of TFA and 32.08% of TFA, respectively). Meanwhile, the monounsaturated fatty acid (MUFA) levels were found to be higher in cooked fish compared to raw one ($p < 0.05$), except for FWSO fish. N-3 PUFA decreased after boiling, oven cooking, FWSO and FWCO from 29.34 to 22.02; 26.67; 4.92 and 4.22% of TFA respectively. However, the level of n-6 PUFA increased particularly for FWSO and FWCO (48.53% of TFA and 46.32% of TFA, respectively). The n-6/n-3 ratio increased in farmed Sea bass after boiling, oven cooking, and FWSO and FWCO from 0.35 to 0.38; 0.59; 10.26 and 12.59 ($p < 0.05$), respectively. After cooking process, oven cooked Sea bass appeared to be the most valuable source of essential n-3 PUFA, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA).

RÉSUMÉ. **-** Effets de différents types de cuisson sur la composition en acides gras des lipides de la chair du bar, *Dicentrarchus labrax* (Moronidae).

Le but de ce travail est de comparer les effets de la cuisson au four, en eau bouillante ou dans deux variétés d'huiles de friture (maïs et tournesol), sur les acides gras des lipides de la chair du bar d'élevage *Dicentrarchus labrax*. La chair du poisson cru est très riche en acides gras polyinsaturés (AGPI) n-3, particulièrement en acide eicosapentaenoïque (EPA) et en acide docosahexaenoïque (DHA), résultant de l'abondance de ces acides gras dans les aliments. Ces AGPI n-3 diminuent respectivement de 29,34 à 4,92 et 4,22% des acides gras totaux (AGT) après friture dans l'huile de maïs et de tournesol ($p < 0,05$). Cependant, les poissons frits présentent des taux élevés d'AGPI n-6 comparés aux témoins (46,32 et 48,53 *vs* 10,24% des AGT) ($p < 0,05$). Le rapport n-6/n-3 varie après cuisson au four, en eau bouillante et après friture dans l'huile de maïs et huile de tournesol de 0,35 chez les témoins à 0,38; 0,59; 10,26 et 12,59, respectivement. La friture dans l'huile de maïs et de tournesol diminue significativement la teneur en EPA et en DHA chez le bar d'élevage.

Key words. - Moronidae - *Dicentrarchus labrax* - Flesh - Cooking procedures - EPA - DHA - n-6/n-3 ratio.

N-3 polyunsaturated fatty acids (PUFA) are known to be essential fatty acids but they are generally deficient in human diet. These fatty acids, especially eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) appear to have antithrombotic, antiinflammatory, antiarhythmic and vasodilatory properties (Lombardo and Chicco, 2006). Regular consumption of food with appropriate content of EPA and DHA provides prevention and treatment of depressions, cardiovascular and some other diseases (Okita *et al*., 2002; Silvers and Scott, 2002).

Aquatic ecosystems are the main source of the two essential PUFA in the biosphere, and humans obtain these

(1) Laboratory of Physiology, Research Unit 05/09/05 "Physiology and Ecophysiology of Aquatic Organisms", Faculty of Medicine, Monastir, TUNISIA. [amira_mnari@yahoo.fr] [Abdelhamid.Chaouch@fmm.rnu.tn] [ibouhlel@yahoo.fr]

(2) Laboratory of Biochemistry, Research Unit 03 ES 08 "Human Nutrition and Metabolic Disorders", Faculty of Medicine, Monastir, TUNISIA. [jrahhanene@yahoo.fr] [med_madiha@yahoo.fr] [Mohamed.Hammami@fmm.rnu.tn]

(3) Department of Biology, Research Unit 05/09/05 "Physiology and Ecophysiology of Aquatic Organisms", Faculty of Sciences, Tunis, TUNISIA. [mhamed.elcafsi@fst.rnu.tn]

* Corresponding author

acids through fish and other marine and freshwater products (Arts *et al*., 2001). Sea bass (*Dicentrarchus labrax*) is highly appreciated by consumers and represents the principal fish species reared in Tunisia. Cooking and other thermal treatments of n-3 PUFA are known to increase their susceptibility towards lipo peroxidation (Regulska-Ilow and Ilow, 2002). Thus, it would explain the decrease of PUFA content in flesh of aquatic species after cooking (Candela *et al*., 1998; Sant'Ana and Mancini-Filho, 2000). However, in some fish species, certain cooking treatments keep constant the PUFA level in flesh (Montano *et al*., 2001). Thus, the fish species and cooking treatments could be determinant factors that control essential fatty acid content of consumed fish.

The effects of frying (Candela *et al*., 1997; Candela *et al*., 1998; Gladyshev *et al*., 2006, 2007), grilling (Garcia-Arias *et al*., 2003a; Garcia-Arias *et al*., 2003b), boiling (Gladyshev *et al*., 2006, 2007) and oven cooking (Candela *et al*., 1998; Türkkan *et al*., 2008) on nutritive values of different fish species have been previously studied. However, there is little information about the changes in the fatty acid compositions of farmed Sea bass. This study was carried out to study the flesh fatty acid composition of raw farmed Sea bass and to examine how different cooking treatments affect fatty acid profiles and concentrations with focus on EPA and DHA contents.

MATERIALS AND METHODS

Materials

Corn and sunflower oils used for frying were purchased at a local store (Monastir, Tunisia). These oils were chosen because they are frequently used for fish frying by Tunisian consumers. All chemical compounds used (chloroforme, methanol, hexane, KOH) were of analytical or chromatographic grade. The external standard fatty acids and nonadecanoic acid methyl ester (internal standard) were obtained from E. Merck (Darmstadt, Germany) and Supelco (Bellefonte, PA, USA).

Cultured Sea bass were obtained in autumn 2008 from the Tunisian Aquaculture Station located in Hergla (Tunisia) (water temperature: 22°C; degree of salinity: 40‰; pH: 8.2). Mean weight and total length at slaughter were 87.0 ± 2.3 g and 19.5 ± 0.5 cm, respectively. They were raised in usual farming conditions, on same conventional food with same feeding techniques. The chemical composition of the food used in this study is given in table I. Animals were transported in ice bath to the laboratory where they were weighed and immediately processed. Five fish were used for each treatment: control, boiling, oven cooking, frying with corn oil (FWCO) and sunflower oil (FWSO). The flesh from each individual from the different treatments was cooked individually.

Table I. - Composition of standard diet fed to farmed Sea bass. Notes: Fatty acids are expressed in % of total fatty acids. [a]Σ SFA (saturated fatty acids) also include C12:0, C14:0, C16:0, C17:0, C18:0, C20:0, C22:0 and C24:0. [b]Σ MUFA (monounsaturated fatty acids) also include C14:1, C16:1 n-7, C17:1, C18:1 n-7, C20:1 n-9, C22:1 n-9 and C24:1 n-9. [c]Σ PUFA n-3 (polyunsaturated fatty acids) also include C18:3 n-3, C20:3 and C22:5. [d]Σ PUFA n-6 also includes C18:3, C20:2, C20:3, C22:2 and C22:4.

	Feed of farmed fish
Proximate composition (% of dry tissue)	
Protein	50.0%
Carbohydrates	12.0%
Ashes	11.5%
Raw fibre	1.5%
Fat	21.0%
FA composition (% total FA)	
C16:0	17.0
C18:1 n-9 (cis)	10.8
C18:2 n-6 (c9.c12)	5.6
C18:3 n-3 (cis)	1.3
C20:4 n-6	1.2
C20:5 n-3	18.6
C22:6 n-3	10.4
Σ SFA[a]	31.2
Σ MUFA[b]	26.3
Σ PUFA n-3[c]	32.3
Σ PUFA n-6[d]	10.1
Σ PUFA	42.4
PUFA/SFA	1.3
n-6/n-3	0.3

Cooking treatments

Common cooking treatments were used: boiling at the temperature of 85-90°C for 10 min and oven cooking under 250°C for 15 min. For frying experiments, a Tefal® frying pan (Ø = 20 cm) was used on an electrical heating unit. After each frying process, the fat that remained in the pan was collected and the pan was cleaned with paper towel. Samples were immersed into frying oil at 180°C. Temperature of frying was controlled by a digital thermometer (Set Testo 106, Nordtek Instrument AB Cöteberg). Samples were fried for 5 min on each side. Pre-experiments were performed to standardize cooking procedures.

Lipid analysis

Flesh samples for fatty acids GLC analysis were taken before and after cooking. One g of flesh was cut and minced. Moisture content of flesh samples were determined by gravimetry at a constant weight in oven at 105°C. Total lipids were extracted with chloroform/ methanol (2:1v/v) according to the method of Bligh and Dyer (1959).

Fatty acid composition of raw and cooked flesh samples was determined by gas liquid chromatography (GLC) analy-

	R	B	OC	FWCO	FWSO
C12:0	nd	nd	0.06 ± 0.01	nd	nd
C14:0	4.05 ± 0.13^{a}	3.5 ± 0.49^{a}	4.19 ± 0.08^{a}	0.76 ± 0.10^{b}	0.68 ± 0.05^{b}
C16:0	19.57 ± 0.19^{a}	19.77 ± 0.16^{a}	19.62 ± 0.17^{a}	13.52 ± 0.47^{b}	8.97 ± 0.31^{c}
C17:0	1.23 ± 0.01^{b}	1.40 ± 0.04^{a}	1.27 ± 0.03^{b}	0.33 ± 0.02^{c}	0.26 ± 0.02^{c}
C18:0	3.94 ± 0.08^{b}	5.18 ± 0.25^{a}	4.14 ± 0.10^{b}	2.46 ± 0.03^{d}	3.42 ± 0.08^{c}
C20:0	0.23 ± 0.01^{b}	0.37 ± 0.06^{a}	0.26 ± 0.01^{b}	0.39 ± 0.02^{a}	0.30 ± 0.02^{b}
C22:0	0.76 ± 0.05^{a}	0.81 ± 0.14^{a}	0.91 ± 0.08^{a}	0.14 ± 0.02^{b}	0.12 ± 0.04^{b}
C24:0	1.75 ± 0.04^{a}	1.65 ± 0.05^{a}	1.63 ± 0.05^{a}	0.22 ± 0.03^{b}	0.19 ± 0.06^{b}
C14:1	0.38 ± 0.01^{a}	0.35 ± 0.03^{a}	0.38 ± 0.01^{a}	0.08 ± 0.01^{b}	0.06 ± 0.02^{b}
C16:1n-7	5.27 ± 0.20^{a}	4.52 ± 0.21^{b}	5.48 ± 0.05^{a}	0.97 ± 0.08^{c}	0.83 ± 0.05^{c}
C17:1	0.92 ± 0.05^{a}	0.84 ± 0.10^{a}	0.96 ± 0.02^{a}	0.21 ± 0.02^{b}	0.13 ± 0.04^{b}
C18:1n9	16.20 ± 0.74^{a}	20.30 ± 1.11^{a}	17.66 ± 0.58^{a}	27.06 ± 0.30^{b}	29.47 ± 0.32^{b}
C18:1n-11	2.89 ± 0.05^{b}	3.34 ± 0.17^{a}	3.03 ± 0.05^{b}	1.04 ± 0.07^{c}	1.09 ± 0.07^{c}
C20:1n-9	1.92 ± 0.03^{a}	2.24 ± 0.24^{a}	1.98 ± 0.07^{a}	0.58 ± 0.03^{b}	0.32 ± 0.11^{c}
C22:1n-9	0.22 ± 0.00^{a}	0.22 ± 0.03^{a}	0.27 ± 0.02^{a}	0.02 ± 0.01^{b}	0.02 ± 0.01^{b}
C18:2n-6	6.27 ± 0.64^{c}	8.58 ± 1.26^{b}	6.14 ± 0.23^{c}	43.88 ± 0.93^{a}	46.23 ± 1.18^{a}
C18:3n-6	0.22 ± 0.00^{a}	nd	0.20 ± 0.00^{a}	0.04 ± 0.02^{b}	0.03 ± 0.02^{b}
C20:2n-6	0.52 ± 0.01^{b}	0.73 ± 0.07^{a}	0.51 ± 0.02^{b}	0.12 ± 0.01^{c}	0.09 ± 0.04^{c}
C20:3n-6	0.14 ± 0.00^{a}	nd	0.15 ± 0.01^{a}	nd	nd
C20:4n-6	1.25 ± 0.12^{a}	1.18 ± 0.05^{a}	1.11 ± 0.02^{a}	0.18 ± 0.02^{b}	0.13 ± 0.05^{b}
C22:2n-6	nd	nd	0.05 ± 0.02^{a}	0.07 ± 0.03^{a}	0.17 ± 0.12^{a}
C22:4n-6	nd	0.19 ± 0.00^{a}	0.21 ± 0.01^{a}	0.27 ± 0.05^{a}	0.06 ± 0.04^{b}
C18:3n-3	0.06 ± 0.03^{a}	nd	0.13 ± 0.01^{a}	nd	nd
C20:3n-3	nd	1.05 ± 0.20^{a}	0.83 ± 0.02^{a}	0.31 ± 0.03^{b}	0.75 ± 0.08^{a}
C20:5n-3	13.24 ± 0.10^{a}	10.75 ± 0.91^{c}	12.61 ± 0.21^{b}	1.74 ± 0.20^{d}	1.72 ± 0.20^{d}
C22:5n-3	0.44 ± 0.01^{a}	0.61 ± 0.09^{a}	0.47 ± 0.01^{a}	0.12 ± 0.02^{b}	0.09 ± 0.03^{b}
C22:6n-3	13.53 ± 0.47^{a}	8.36 ± 1.79^{b}	11.29 ± 0.43^{b}	1.60 ± 0.26^{c}	1.37 ± 0.43^{c}

Table II. - Fatty acid levels (% of total fatty acids) in raw and cooked farmed Sea bass. Notes: mean values from four samples ± SE. Values in the same row bearing different letters are significantly different ($p \leq 0.05$). nd: not detected; R: raw; B: boiled; OC: oven cooked; FWCO: fried with corn oil; FWSO: fried with sunflower oil.

sis of fatty acid methyl esters (FAME). FAME were prepared from total lipids by saponification and methylation using 2M KOH in methanol and n-hexane using the method of Ichihara *et al*. (1996), modified as follows: 10 mg of extracted fat were dissolved in 2 ml hexane followed by 4 ml of 2M methanolic-KOH in a tube. The tube was then vortexed for 2 min at room temperature and the hexane layer was taken up for GLC analysis. GLC FAME analysis was carried out in a Hewlett-Packard (HP 5890) chromatograph (Hewlett-Packard Ca Palo Alto, Calif), an injector split ratio 1:50, and a flame-ionization detector (FID) linked to an HP Chemstation integrator. A fused silica capillary column DB23 (60 m x 0.32 mm id x 0.25 μm as film thickness, HP-Agilent Technologies, Wilmington) was used with nitrogen as the carrier gas at a flow rate of 0.44 ml/mn, a flame ionization detection temperature of 280°C, an injector temperature of 270°C and an oven temperature programmed from 130 to 250°C. Standard FAME were separated in the same GLC conditions. FAME from flesh samples were identified by comparing their respective retention times with those of standard mixtures. The area of each peak was automatically integrated and FAME amount was calculated using nonadecanoic acid methyl ester (C19:0) as internal standard.

Fatty acids were expressed as percentage of total FAME or in absolute content (g/100 g of food). Two indexes that take into account the different atherogenic and thrombogenic potential of some fatty acids were calculated.

The atherogenic index (AI) (De Lorenzo *et al*., 2001) was defined by the equation (1):

(1) $AI = (C12:0 + C14:0 + C16:0) / (n\text{-}3PUFA + n\text{-}6PUFA + MUFA)$

where MUFA are monounsaturated fatty acids.

The thrombogenic index (TI) (De Lorenzo *et al*., 2001) was defined by the equation (2):

(2) TI = (C14:0 + C16:0 + C18:0) / (0.5n-6PUFA + 3n-3PUFA + n-3PUFA/ n-6PUFA)

Statistical analysis

The descriptive statistics (mean standard values from four samples ± standard error) and one-way analysis of variance were conducted using a statistical analysis system (SPSS Version 12). Significant differences among the studied samples were determined by an analysis of variance (one way ANOVA), which applied a Tukey's test at $p < 0.05$.

RESULTS

Distribution and amount of individual fatty acids in raw and cooked samples of farmed Sea bass are given in table II. The percentage of saturated fatty acids (SFA), MUFA, n-3 PUFA and n-6 PUFA in raw and cooked fish are presented in figure 1. In raw Sea bass, our results revealed that PUFA amounting to 39.6% of total fatty acids (TFA) were prevalent over the SFA (31.5% TFA) and MUFA (28.8% TFA) fractions. Palmitic acid (C16:0) was the primary SFA, contributing to 62% of the total SFA content of lipids. As for MUFA fraction, oleic acid (C18:1 n-9) was predominant (16.2% TFA) over palmitoleic (C16:1 n-7) (5.27% TFA) and cis vaccenic (C18:1 n-7) (2.9% TFA) acids. DHA (C22:6n-3; 13.5% TFA) was the prominent PUFA in raw Sea bass followed by EPA (C20:5n-3; 13.2% TFA) and linoleic acid (C18:2n-6) (6.3% TFA).

The effects of different cooking processes: boiling, over cooking and FWCO and FWSO on moisture and fat in farmed Sea bass are given in table III. After cooking process, minimum moisture value was characteristic of fish FWSO (21.6 ± 6%) while maximum moisture was found in boiled and oven cooked fish (72.5 ± 1% and 69.0 ± 1.2%, respectively). The total fat content decreased significantly after boiling and oven cooking. However, FWCO and FWSO farmed sea bass resulted in a significant increase in fat contents (expressed in mg/g wet matter) from 86.6 ± 13 to 120.0 ± 14 and 125.0 ± 8 ($p < 0.05$).

Table III. - Moisture and fat contents of raw and cooked farmed Sea bass. Notes : mean values from four samples ± SE. Values in the same row bearing different letters are significantly different ($p \leq 0.05$). R: raw; B: boiled; OC: oven cooked; FWCO: fried with corn oil; FWSO: fried with sunflower oil. Fat content was expressed in mg/g wet matter.

	Farmed Sea bass				
	R	B	OC	FWCO	FWSO
Moisture content (%)	76.2 ± 2.2^{a}	72.5 ± 0.09^{ab}	69.0 ± 1.2^{b}	51.4 ± 5^{c}	21.6 ± 6^{d}
Fat content (mg/g)	86.6 ± 13^{a}	38.7 ± 5.3^{b}	52.7 ± 4.7^{c}	120.0 ± 14^{d}	125.0 ± 8^{d}

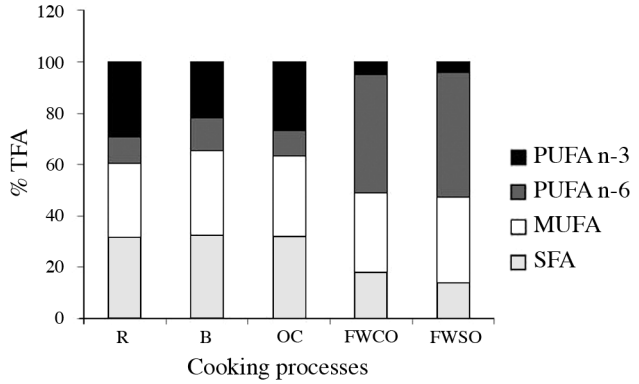

Figure 1. - Total SFA, MUFA, PUFA n-6 and PUFA n-3 concentration in raw and cooked farmed Sea bass. Mean values from four samples ± SE. R: raw; B: boiled; OC: oven cooked; FWCO: fried with corn oil; FWSO: fried with sunflower oil.

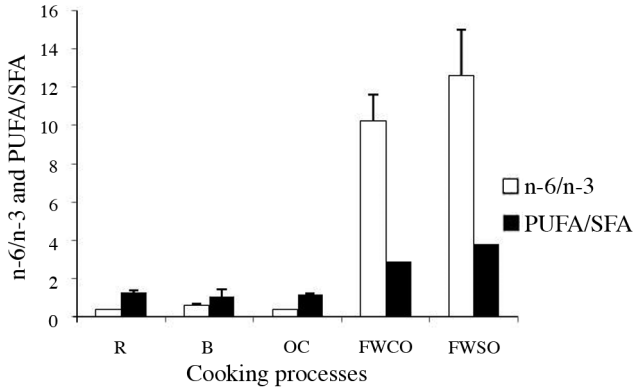

Figure 2. - n-6/n-3 and PUFA/SFA ratios in raw and cooked farmed Sea bass. Mean values from four samples ± SE. R: raw; B: boiled; OC: oven cooked; FWCO: fried with corn oil; FWSO: fried with sunflower oil

SFA increased after boiling and oven cooking but they decreased significantly in farmed Sea bass FWSO and FWCO ($p < 0.05$) (Fig. 1). FWCO and FWSO farmed sea bass resulted in a large and significant decrease in (C16:0) from 19.6% to 13.5% and 9.0% respectively ($p < 0.05$). MUFA increased after all cooking processes. Differences observed were statistically significant only for oven cooked and FWSO fish ($p < 0.05$). Oleic acid increased after all cooking processes. Differences observed were statistically significant ($p < 0.05$) except for oven cooked farmed Sea bass.

N-6 PUFA remained stable after boiling and oven cooking treatments in farmed Sea bass but they increased significantly particularly (C18:2n-6) in fish FWCO and FWSO with a percentage gain of about 85.7% and 86.4%, respectively ($p < 0.05$) (Fig. 1; Tab. II). All cooking ways led to a significant ($p < 0.05$) decrease of n-3 PUFA levels especially of DHA and EPA in Sea bass flesh (Fig. 1; Tab. II). N-6/n-3

ratio increased significantly after boiling ($p < 0.05$) (Fig. 2). The most important increase of n-6/n-3 ratio was observed after FWCO and FWSO from 0.35 to 10.2 and 12.6, respectively. The PUFA/SFA ratio decreased after boiling and oven cooking but increased significantly ($p < 0.05$) after FWCO and FWSO from 1.2 to 2.8 and 3.8, respectively. Moreover, our results also revealed that AI remains stable after boiling and oven cooking (0.34 and 0.35) but decreased after FWCO and FWSO from 0.34 to 0.17 and 0.11 ($p < 0.05$), respectively. However, TI increased in farmed Sea bass from 0.28 to 0.37, 0.32, 0.44 and 0.35, respectively after boiling, oven cooking and FWCO and FWSO ($p < 0.05$).

DISCUSSION

Our results showed that the fatty acid profile in raw Sea bass exhibited a dominance of SFA and PUFA. It was probably due to the fact that the food used for farmed sea bass is rich in PUFA and SFA (Tab. I). Abundance of PUFA and SFA in farmed fish has also been reported by Alasalvar *et al*. (2002) and Saglik *et al*. (2003) for Sea bass. Oleic acid was identified as the primary MUFA in farmed Sea bass in the present study. The high amount of oleic acid in farmed Sea bass is believed to arise from its dominance in commercial food (Grigorakis *et al*., 2002). In our study, the food contained 10.8% of oleic acid (Tab. I). N-3 PUFA were concentrated in farmed fish with lower n-6 PUFA levels. Among n-6 PUFA, linoleic acid was the major fatty acid. This is due to the high level of linoleic acid (5.6%) in the farmed feed compared to the arachidonic ones (1.2%). Linoleic acid is usually found in high amounts in farmed Sea bass and Sea bream (Alasalvar *et al*., 2002; Grigorakis *et al*., 2002; Saglik *et al*., 2003; Mnari *et al*., 2007). Linoleic acid is present in plant oils used in the diet of farmed fish and accumulates in the lipids of marine fish without being changed because of their reduced capacity for chain elongation and desaturation (Yamada *et al*., 1980). Thus, the high amount of linoleic acid in farmed fish appears to be related to the feed composition (Alasalvar *et al*., 2002; Grigorakis *et al*., 2002; Saglik *et al*., 2003). In contrast, the level of aracidonic acid (C20:4 n-6) was low in farmed Sea bass, because the dietary fish used contained minimal amounts of this fatty acid (1.2%). EPA and DHA were the major n-3 PUFA in farmed Sea Bass reflecting the fatty acid composition of the food used in the aquaculture station. Thus, our study suggests that there is a strong relationship between the lipid composition of the farmed Sea bass and that of its diet as it has been reported for other species (Pirini *et al*., 2000; Grigorakis *et al*., 2002).

Our results revealed a decrease in the total fat content in boiled and oven cooked fish. FWCO and FWSO significantly increased the total fat content and resulted in a decrease in the moisture content. Similar results were reported by Türkkan *et al*. (2008) for fried Sea bass. The loss of moisture in fish FWSO was more important than that observed in FWCO. These compositional changes were due to the absorption of lipids from the frying medium and also to the loss of water, which occurred during the cooking process (Al-Saghir *et al*., 2004). In general, the possible mechanisms for the changes, which may take place during culinary preparation include the absorption of the cooking fat, the leaching of fat-soluble molecules from the fish together with oxidation reactions which generate free radicals in the hot cooking fat (Little *et al*., 2000). Hence, control over the composition of the fried fish can be achieved to some extent by selection of the cooking fat. Vegetable oils are not equally susceptible to frying process due to the differences in the composition, saturation level of their component fatty acids and their antioxidant content (Kamal-Eldin, 2003).

The levels of SFA decreased after FWCO and FWSO due to the important reduction of palmitic acid. Our results were similar to those reported by Candela *et al*. (1998) for fried mackerel (*Scomberomorus commersoni*) and sardine (*Sardine pilchardus*), by Gladyshev *et al*. (2006, 2007) for fried humpback Salmon (*Oncorhynchus gorbuscha*) and herring (*Clupea harengus pallasi*), and by Türkkan *et al*. (2008) for fried Sea bass.

Oleic acid (C18:1 n-9) increased after all cooking processes, particularly after FWCO and FWSO. Such an increase was also mentioned by Sanchez-Muniz *et al*. (1992) for fried sardine, by Candela *et al*. (1998) for fried mackerel and sardine, by Al-Saghir *et al*. (2004) for steamed and fried salmon, by Gladyshev *et al*. (2006, 2007) for fried humpback salmon and herring, and by Türkkan *et al*. (2008) for fried Sea bass. The significant increase observed after frying with both oils was probably a consequence of absorption from the cooking medium, which is rich in this fatty acid. This reflects the development of a fatty acid gradient equilibrium between fish being fried and that of oils used for cooking. These results are in accordance with that of Sioen *et al*. (2006) for pan-fried salmon and cod (*Gadus morrhua*) and by Candela *et al*. (1998) for deep-fried sardines.

Despite this increase, the MUFA total content changed slightly in fried fish compared to raw fish because of the simultaneous loss of other MUFA, particularly in palmitoleic acid (C16:1n-7). In fact, the different frying effects on SFA and MUFA depend on the initial fat content of the fish as well as to the cooking oils (Mai *et al*., 1978; Gall *et al*., 1983; Candela *et al*., 1998).

The significant increase in linoleic acid (C18:2n-6) after frying in sunflower oil was also mentioned by Candela *et al*. (1997) in sole (*Solea solea*), cod and hake (*Merluccius merluccius*) after FWSO and by Al-Saghir *et al*. (2004) in salmon (*Salmon salar*) after FWCO. This is likely due to the absorption of this fatty acid from the cooking medium.

The changes in fatty acid content after different cooking ways were marginal, in particular for the most important n-3 PUFA, EPA and DHA. The most important decreases were observed in fish FWCO and FWSO. Similar results for DHA and EPA were observed in humpback salmon after FWSO (Gladyshev *et al*., 2006). The significant effect of frying on EPA and DHA contents can be explained by oil absorption. The long chain of polyunsaturated fatty acids in fish and fish oils, such EPA and DHA are considered to be highly susceptible to oxidation during heating and other culinary treatments (Candela *et al*., 1998; Sant'Ana and Mancini-Filho, 2000; Kulas and Ackman, 2001; Tarley *et al*., 2004).

Our results also showed that 95% of the amount of EPA and 83% of DHA present in raw farmed sea bass will be ingested when eating ovencooked fish. However, only about 13% of the amount of EPA and 11% of DHA initially present in raw fish will still be available to the consumer after FWSO or FWCO. Thus, our study clearly shows that an intake assessment of fatty acids based on raw fish differs significantly from an assessment based on prepared fish. In Tunisia, fish is cooked using different methods but frying is the most popular. As the result, it would be healthier for the consumer to focus on ovencooking rather than oil frying in order to preserve the quality of the raw farmed Sea bass characterized by a wealth of EPA and DHA.

The significant increased loss in n-6 PUFA and n-3 PUFA in fried Sea bass explain their high n-6/n-3 ratio and PUFA/SFA ratio values compared to that of raw fish. Moreover, the PUFA/SFA ratio was significantly different when using the two types of oil. The PUFA/SFA ratio increased 2.3 and 3 times respectively after FWCO and FWSO. Sanchez-Muniz *et al*. (1992) have also reported that the PUFA/SFA ratio increased 4.1 times for sardine FWSO. This can be attributed to the high levels of MUFA and PUFA in oils.

Besides PUFA content, n-6/n-3 ratio is known to be of dietetic importance because it is the key factor for balanced synthesis of eicosanoids in the organism (Steffens, 1997). According to the current recommendations, daily n-6/n-3 ratio in total human diet should be lower than 5 (Vujkovic *et al*., 1999). The ratio of n-6/n-3 increased 1.7 times after boiling, 1.1 times after oven cooking, 29.3 times after FWCO and 36 times after FWSO oil. Although the increase of the PUFA/SFA ratio should be beneficial, the change of the ratio n-6/n-3, that takes place at the same time does not seem to be adequate. This ratio increase affects the benefits related to the EPA and DHA intake.

Furthermore, the potential clinical effect of EPA and DHA can be better evaluated by mean of lipid quality indices. The AI decreased only after FWCO and FWSO. However the TI increased in farmed Sea bass after all cooking processes. The lipid quality indexes obtained were similar to those reported by Poli *et al*. (2003), by Rondán *et al*. (2004) and Ballestrazzi *et al*. (2006) for other fish species and to those of other foodstuffs, that are advisable for human consumption (Perez-Llamas *et al*., 1998). Our results revealed that AI was clearly affected by linoleic acid increase and TI by decrease of EPA + DHA.

One of the most prominent results of our study is the modest reduction in EPA and DHA contents in farmed Sea bass during boiling and oven cooking and the significant important reduction after FWCO and FWSO. Other authors reported a PUFA decrease including EPA and DHA during grilling (Ohshima *et al*., 1996) and canning (Tarley *et al*., 2004). These different effects may be due to the differences in cooking ways, such as temperature and oil, but may also be species specific.

In conclusion, the lipid fraction in farmed sea bass was characterized by a high proportion of n-3 PUFA, particularly EPA and DHA, reflecting the fatty acid composition of the diet used in the aquaculture station. Frying farmed Sea bass in the two oil varieties decreased SFA and n-3 PUFA contents, but increased particularly n-6 PUFA, limiting the positive effects of the high n-3 PUFA level in raw flesh of farmed Sea bass. As a result, oven cooked and boiled farmed Sea bass were regarded to be suitable items in the human diet concerning EPA and DHA, because of their relative stability during oven cooking and boiling processes.

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